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Development of a Technique to Assess the Adequacy of the Municipal Water Supply for a Residential Sprinkler System

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Abstract

This research effort developed a technique to assess the adequacy of the municipal water supply for residential sprinkler systems installed in one- and two-family dwellings. This effort is a continuation of a recently completed project which investigated cost-effective techniques for alleviation deficiencies in the municipal water supply. In that effort , a need was identified to develop a technique to evaluate the adequacy of the municipal water supply.

This report includes characterizing typical plumbing flow fixtures in residences to permit an analysis of the domestic water supply within a residence. Having characterized the residential flow devices, techniques to evaluate the domestic water supply are investigated. This investigation considers the feasibility of developing an inexpensive prototype apparatus with which to conduct the water supply evaluations.

Based on the water supply evaluations, an assessment of the adequacy of typical domestic water systems for satisfying water demand requirements of residential sprinkler systems are documented. The water demand requirements for residential sprinkler systems were selected from the initial phase of this research which investigated techniques to alleviate water supply deficiencies.

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1. INTRODUCTION

In a previous report, Milke and Bryan [1] identified two measures that could supplement or be used in lieu of a municipal water distribution system to adequately supply a residential fire sprinkler system. The two measures included a pump and a combination pump-tank system. Cost estimates were provided for the pump and combination pump-tank, as well as the advantages and disadvantages of each of the two supplementary measures. However, in the previous effort, little attention was given to determining when the municipal water supply was deficient such that the supplementary measures would be required.

This report documents the subsequent effort to develop a simplified approach for homeowners to assess the adequacy of the doemstic water supply system to supply a residential sprinkler system. Since homeowners are the anticipated users of this approach, any required measurements must be easy to obtain and any subsequent analysis must be elementary. Due to the emphasis on simplicity, some accuracy will need to be sacrificed. As a result, this approach is intended only to allow homeowners to approximately assess the adequacy of the municipal water supply system to supply a residential sprinkler system. In essence, through the approach outlined in this report, homeowners should be able to determine if the level of adequacy of the municipal water supply system is in one of the following categories: adequate, marginal or inadequate.

As a part of the effort, residential plumbing fixtures (to be used to collect measurements) were characterized. The

applicability and utility of the analysis technique was evaluated through a series of field tests conducted at randomly selected residences in the Baltimore, Maryland - Washington, D.C. metropolitan area.

This report addresses the adequacy of a municipal water supply system in two steps. The adequacy of any system needs to be assessed relative to the assumed demand on that system. Thus, in the context of this report, the adequacy of a municipal water supply system is addressed relative to the particular application of supplying a residential sprinkler system from the domestic water system. A municipal water supply system is considered to be adequate if the available residual pressure is greater than the demand pressure at the required water flow rate. First, the demand requirements of the residential sprinkler system must be determined. In the second step, the characteristics of the domestic water supply system are evaluated.

2. WATER SUPPLY REQUIREMENTS

Minimum water flow requirements for automatic residential sprinkler systems are stipulated in NFPA 13D, "Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes" [2]. Considering these stipulations, hydraulic analyses were conducted by Coutts and Clark [3] to determine the water demand requirements associated with residential sprinkler systems for seven residences. The water demand requirements were expressed in terms of the water flow rate and pressure demand requirements for a residential sprinkler

system at the point of cross-connection with the domestic water system. A complete review of the hydraulic analyses has been included elsewhere [1,3].

A summary of the water supply demand requirements at the cross-connection point, as determined by Coutts and Clark [3], is presented in Table 1. As expected, in each of the seven residences, the required demand pressure is greater for the designs using 3/4 inch CPVC pipe than for the designs with 1 inch CPVC pipe. As indicated in Table 1, the demand pressure ranged from 28.7 to 49.4 psi (at flow rate of 26 gpm) for a sprinkler system with 3/4 inch CPVC pipe. Using 1 inch CPVC pipe, the range of the demand pressure required to provide a flow rate of 26 gpm was 19.2 to 36.6 psi.

Additional observations can be noted comparing the demand pressure requirements for the cases of one or two operating sprinklers. Considering the designs with 1 inch CPVC pipe, the demand pressure required in all seven residences for the one operating sprinkler condition with a water flow rate of 18 gpm (34 lpm) was greater than the demand pressure associated with the condition of two operating sprinklers discharging a combined water flow rate of 26 gpm (49 lpm).

Initially, this observation may be surprising. The basis of the higher demand pressure required for the one operating sprinkler case can be pinpointed by examining the details of the hydraulic analysis conducted by Coutts and Clark. The sprinkler head used in all of the designs had a K factor of 3.85 [3]. In order to discharge a particular flow rate, Q (gpm), from one

sprinkler head, the pressure, P (psi), required at the sprinkler head can be determined from equation [1].

$$Q = K (P)^{0.5} \tag{1}$$

where:

Q : water flow rate (gpm)

K : nozzle/orifice coefficient

P : Orifice pressure (psi)

A pressure of 21.9 psi is required at the sprinkler head to deliver a flow rate of 18 gpm. In contrast, only 11.4 psi is required at each of two sprinkler heads delivering 13 gpm, each (for a total of 26 gpm). Based on the pressure required at the sprinkler head, the one operating sprinkler head design requires an additional pressure of 10.5 psi as compared to the two sprinkler head design.

Only a minor amount of this difference in the pressure at the sprinkler head is offset by the commensurate increase in friction loss associated with the increase in flow rate from 18 to 26 gpm. The friction loss per foot for 1 inch CPVC pipe with a water flow rate of 18 gpm is 0.054 psi. Comparatively, the friction loss per foot for 1 inch CPVC pipe with a water flow rate of 26 gpm is 0.107 psi. Thus, even with 100 ft of pipe (the greatest amount of pipe between the supply point and the operating sprinkler for the seven residences was only on the order of 80 ft, including the effect of valves and fittings), the additional friction loss for the water flow rate of 26 gpm as compared to that for 18 gpm is only 5.3 psi. The net difference

in the demand pressure for the two assumed water flow rates, accounting for the differences in pressure required at the sprinkler head and friction loss, is approximately 6 psi. As indicated in Table 1, the actual difference in demand pressure required for the seven residences ranges from 4.1 to 8.1 psi, with an average difference of 6.2 psi.

As compared to the case of 1 inch pipe, the demand pressure for the 3/4 inch pipe design is only greater in four residences for the case of one operating sprinkler as compared to the demand pressure for two operating sprinklers. Since the pressure required at the operating sprinkler head is independent of pipe diameter, the same 10.5 psi difference in pressure required at the sprinkler head for one versus two operating sprinklers can be expected for the 3/4 inch pipe.

However, the friction loss is dependent on pipe diameter. the friction loss per foot of 3/4 inch CPVC pipe with a flow rate of 18 gpm is 0.163 psi. Comparatively, the friction loss per foot for 3/4 inch CPVC pipe with a water flow rate of 26 gpm is 0.322 psi. Thus, with 100 ft of pipe the additional friction loss for the water flow rate of 26 gpm is only 15.9 psi. The additional friction loss for the water flow rate of 26 gpm offsets the decrease in pressure required at the operating sprinkler head(s). Since all of the residences did not include the same length of pipe, the friction loss differential was not constant. Still, the friction loss differential was still great enough in four residences to offset the operating sprinkler head pressure differential.

Upon reviewing the work by Coutts and Clark, a simplified calculation procedure for determining the water demand requirements of a residential sprinkler system is proposed in Table 2. The method consists of an elementary hydraulic calculation method to determine the pressure differential between two points caused by friction loss and elevation change. The principal simplification consists of the elimination of the need to account explicitly for the assortment of valves and fittings included in the system. Instead, the length of piping is estimated by determining the right angle distance to the most remote point in the house from the cross-connection point (see Figure 1). Since the piping is likely to terminate at the most remote sprinkler head, located up to six feet away from the walls, some additional piping has been included in the estimation procedure (see dimensions "A" and "B" in Figure 1). The additional length included to reach the corner of the residence serves to account for the additional friction loss associated with the valves and fittings, which are not otherwise accounted for in this short estimation technique.

The effect of accounting for the valves and fittings through the increased pipe length can be observed in terms of the good agreement of the estimated residual pressure required with that obtained from a detailed hydraulic analysis. A comparison of the results of the proposed, simplified procedure for the seven residences with the requirements calculated by Coutts and Clark using an elaborate hydraulic analysis is presented in Table 3. The comparison of the two calculation procedures is provided for

the design conditions of one and two operating sprinklers. As indicated in the table, the agreement between the two methods is very good, with the calculations for the Ranch House (Style 1) being the exception. The poor agreement in this case for two operating sprinklers is attributed to the unique design characteristics of the sprinkler system for this residence. Specifically, the sprinkler heads selected for the design calculation in this residence were not located on the same branch line, thereby reducing the demand pressure requirement. Otherwise, the calculation procedure estimates the required pressure within 3 psi in 22 of 28 total designs (each combination of pipe size, number of operating sprinklers and residence comprises a "design") and 5 psi in 26 of 28 designs of that determined by the hydraulic analysis. The average difference between the simplified procedure and the elaborate hydraulic calculation approach is 2.2 psi. In a majority of designs, the proposed calculation technique provides a conservative estimate of the pressure requirement, i.e. slightly overestimates the demand residual pressure.

A further simplification of the analysis technique outlined in Table 2 can be suggested based on a review of the basic parameters affecting the demand pressure. The three basic parameters which determine the demand pressure are sprinkler orifice pressure, friction loss and elevation change. The sprinkler orifice pressure is either 11.4 psi (for a water discharge rate of 13 gpm from each of two operating sprinklers) or 21.9 psi (for a water discharge rate of 18 gpm from one

operating sprinkler). The friction loss is dependent on the diameter and length of pipe and number and type of fittings. For 3/4 inch CPVC pipe with one operating sprinkler, the friction loss for the seven residences varies from 8.7 to 12.8 psi (see Table 3). With two operating sprinklers, the friction loss with 3/4 inch CPVC pipe varies from 17.1 to 25.2 psi. Likewise, the friction loss for 1 inch CPVC pipe varies from 2.9 to 4.2 psi for one operating sprinkler and 5.7 to 8.4 psi for two operating sprinklers. The variation of friction loss for the two pipe diameters and two design conditions (one or two operating sprinklers) is not substantial. Thus, considering the objective of formulating an elementary estimation procedure, the maximum friction loss for each of the combinations of pipe diameter and number of operating sprinklers can be used. As an example, the friction loss for a sprinkler system design using 3/4 inch CPVC pipe for two operating sprinklers will be estimated as 25 psi (for 78 ft of pipe).

Based on the above observations, the outline of an elementary method for determining the pressure demand required is given in Table 4. The first three lines of the procedure are the same for sprinkler system designs using either 3/4 or 1 inch pipe. Line 4 is used for sprinkler systems with 3/4 inch pipe only. 1 inch sprinkler system designs are examined in Lines 5 and 6. The additional line for 1 inch designs is needed to calculate the demand pressure requirements for both the 18 gpm and 26 gpm water flow rates. Both calculations are needed since the demand pressure for 26 gpm in less than that for 18 gpm.

Thus, domestic water system considered to be adequate must be capable of satisfying both demand pressure requirements. According to this elementary estimation procedure, the demand pressure for sprinkler system designs with 3/4 inch pipe will always be greater for the flow rate of 26 gpm than for 18 gpm due to the differential in the friction loss being larger than the differential in sprinkler operating pressures.

A comparison of the results of the elementary technique (Table 4) with that calculated by the elaborate hydraulic analysis method [3] and the first simplified method (Table 2) is provided in Table 5. As indicated in the table, the agreement of the elementary method with the other two approaches is very good. Typically, the elementary method provides demand pressures which are slightly greater than that of the other two methods with the exception of Ranch House - Style 1 and the Split Level (3/4 inch design only). The poor agreement for the Ranch House - Style 1 is attributed to the same cause given for the poor agreement with the simplified technique, provided previously. The substantial overestimation of the demand pressure by the elementary technique as compared to the elaborate hydraulic analysis method for the Split Level, 3/4 inch CPVC pipe design by 10.6 psi is due to the overestimation of the friction loss. The friction loss for the Split Level was estimated in Table 3 as being 17 psi (for an estimated length of pipe of 53 ft), instead of the 25 psi value (associated with a length of 78 ft) assigned in Table 4 for all 3/4 inch CPVC pipe designs.

The elementary calculation procedure estimates the required demand pressure within 3 psi in 16 of 21 total designs (each combination of pipe size, number of operating sprinklers and residence comprises a "design") and 5 psi in 19 of 21 designs of that determined by the hydraulic analysis. The average difference between the elementary method and the elaborate hydraulic calculation approach is 2.7 psi.

Similarly, comparing the results from the two estimation methods, the elementary calculation procedure estimates the required demand pressure within 3 psi in 19 of 21 total designs (each combination of pipe size, number of operating sprinklers and residence comprises a "design") and 5 psi in 20 of 21 designs of that determined by the hydraulic analysis. The average difference between the elementary method (Table 4) and the simplified procedure (Table 2) is 1.4 psi.

Despite the two substantial overestimations, the elementary approach is considered useful since the errors are on the conservative side and the elementary approach requires very little expertise to apply. Further, the elementary method provides results which are very similar to those obtained by the simplified method, which includes more steps and fewer assumptions. If the water supply is not able to meet the demand pressure, conservatively estimated by the elementary approach, then prior to supplementing the water supply, application of one of the other two calculation methods may be desired. The other calculation techniques may provide a more accurate estimate of the demand pressure. Through the application of more accurate

methods, it is possible that a solution will be provided to indicate the domestic water supply is adequate. This is especially possible if the water supply is judged to be close to meeting the demand pressure calculated by the elementary approach.

3. DETERMINING THE WATER SUPPLY CHARACTERISTICS

3.1 Flow Tests with Fire Hydrants

Traditionally, a flow test is conducted by the water authority to determine the characteristics of the municipal water supply system [4]. Such a flow test should consist of taking measurements using at least two fire hydrants. The measurements obtained include the static pressure and residual pressure at one fire hydrant and the water flow rate at the second hydrant. Many municipal water authorities have data from recently conducted flow tests at fire hydrants throughout the municipal water distribution system.

In order to determine the characteristics of the water supply within a residence using data obtained from a flow test conducted at a fire hydrant by the water authority, a hydraulic analysis is required. The hydraulic analysis addresses the pressure changes between the test point, i.e. fire hydrant, and the cross-connection point and determines the pressure available for any required flow. The change in the residual pressure will occur as a result of friction loss and any net variation in elevation between the two points. A net variation in elevation will also affect the static pressure (no water flow condition),

thereby requiring the static pressure to be adjusted to account for the elevation changes.

A hydraulic analysis is an elementary task for technically oriented individuals. However, collecting the necessary information for the analysis may not be trivial. The information required to conduct such an analysis would include the size and configuration of the piping; number and type of fittings, valves and meters; and net elevation change between the test hydrant and the cross-connection point of the sprinkler system with the domestic water system. Much of the necessary data could be acquired by consulting with technical representatives of the municipal water authority. Most likely, the friction loss data for valves and meters obtained from the municipal water authority will be for "generic" units, as a variety of valves and meters may be installed in a municipal water distribution system. It should be noted that the friction loss characteristics for valves and meters produced by a particular manufacturer may be appreciably different than for "generic" units. However, the difference in characteristics between a specific valve and a "generic" unit should not be significant for the approximate analysis considered in this study. In addition, the accuracy of water flow data obtained from a water authority may be questionable as a substantial amount of time may have passed since the most recent flow test conducted at the fire hydrant closest to the residence.

3.2 Flow Tests Using Residential Plumbing Fixtures

As an alternative, a flow test conducted at the residence would alleviate the need to contact the water authority as well as manufacturers of valves and fittings for data. Lawn sprinkler system contractors have been conducting water flow tests using residential garden hose faucets for several years in order to characterize the domestic water system. An example of the measurement apparatus used by the lawn sprinkler system contractors for the flow test is illustrated in Figure 2 [5]. The apparatus includes a pressure gage to measure the static and residual pressure (in psi) and a flow gage to measure the water flow rate (in gpm). The results of the flow test are used to estimate the need for a pump as well as to determine the pipe size needed. Essentially, the need for a pump is made subjectively by noting only the water flow rate and relative magnitudes of the static and residual pressures. Generally, no detailed analysis is performed by lawn sprinkler contractors to consider the characteristics of the residential water system supplying the water to the faucet which can appreciably influence the results of the flow test.

As previously noted, the information acquired from a flow test conducted using a plumbing fixture is identical to that acquired using a fire hydrant, i.e. static pressure, residual pressure and water flow rate. Following the collection of such data, a hydraulic analysis must be conducted to determine the characteristics of the domestic water system at the cross-connection point, as well as to determine the available pressure

at the demand flow, e.g. 26 gpm. As in the case involving the use of a fire hydrant, only technically oriented individuals may be capable of conducting a comprehensive hydraulic analysis. However, in the interest of having a method which many homeowners may be able to apply, the basis for a simplified hydraulic analysis will be described in this report.

The following information is needed in order to conduct the hydraulic analysis: piping size and configuration; number and type of fittings and valves; and net elevation variation between the plumbing fixture and the proposed cross-connection point of the sprinkler system with the domestic water system. The noted information is similar to that required for the water flow test at a fire hydrant, except in the case of water flow tests with a plumbing fixture, the information may be easier to acquire. Data pertaining to the hydraulic characteristics of piping, valves and many types of fittings for domestic water systems are readily available [2,5,6]. Hydraulic characteristics of selected plumbing fixtures, i.e. hose bibbs and boiler drains, have been determined as a part of this project and also are presented in the next section.

In some cases, problems may be encountered in obtaining the necessary data for a hydraulic analysis where piping, fittings and valves are located within wall assemblies, thereby being obscured from view. As a result of the obscuration, the homeowner may be unable to determine the number of fittings, exact length of pipe, etc. Thus, the data requirements need to be further simplified, even though a simplification will result

in a loss in accuracy. However in the context of this study, such a loss in accuracy is not critical since the principal objective of the calculation method is to provide the means by which homeowners, with little technical expertise, can determine the adequacy of the water supply system only in approximate terms. As noted before, the primary purpose of the calculation method is to determine which of the following three categories best describes the adequacy of the domestic water supply system relative to its ability to supply a residential sprinkler system: adequate, marginal, or inadequate.

The simplified method to estimate the water supply characteristics of the domestic water system makes use of the following information:

* type of piping (copper types K,L,M or PVC Schedule 40)
* diameter of pipe (1/2" to 1")
* right angle distance from test faucet to cross-connection point (in feet)
* size of pressure reducing valve (if present) (1/2" to 1")
* net elevation variation between test fixture and cross-connection point (in feet)
* type of plumbing fixture used as test fixture

The type of piping affects the friction loss characteristics of the pipe. Specifically, the material type (copper versus PVC) dictates the roughness of the internal pipe wall. Copper is considered to have a C value (roughness coefficient) of 140, whereas PVC has a C value of 150 [5-7]. In addition, the pipe type also dictates the inner and outer diameters of the pipe.

For example, for nominal 1/2", 3/4" and 1" pipe, the internal diameters for the four commonly used pipe types in residential cold water systems are noted in Table 6 [5-8].

The friction loss per unit length for a given flow rate is inversely proportional to the diameter of the pipe. Generally, the diameter of pipe used (from 1/2" to 1") in a domestic plumbing system is selected based on the number of fixtures supplied by the pipe.

The right angle distance from the test fixture to the cross-connection point is measured as illustrated in Figure 3, being the sum of both dimensions "D" and "E".

The purpose of a pressure reducing valve (PRV) is to limit the pressure in the domestic water system in order to prolong the life of plumbing fixtures and appliances. In many jurisdictions, PRV's are required by plumbing codes. However, it is possible that a particular residence may have been constructed prior to the adoption of such codes or may be located in a jurisdiction which has not adopted a requirement for PRV's. The size of the PRV can be determined by noting the diameter of the pipe connected to the valve, i.e. if 3/4" pipe is connected to the valve, the PRV is referred to as a 3/4" valve. Examples of the PRV's used for residential applications are illustrated in Figure 4 [9-11].

The net elevation variation between the test fixture and the cross-connection point is required to account for the elevation head, which affects both the static and residual pressures. The

variation is determined by measuring the vertical height between the test fixture and the cross-connection point.

The cross-connection point is the position within the residence on the domestic water system where the sprinkler system will be connected. If possible, the cross-connection point should be located before the PRV. Local water authorities may require the cross-connection point to be located before the water meter [1]. If the water meter is underground and located outside of the residence, the cross-connection point may be considered, for the purpose of this study, as the point where the domestic water service penetrates the exterior wall of the residence.

Finally, the flow characteristics of the test fixture must be known. Examples of different types of test fixtures which have already been characterized are illustrated in Figure 5 [12]. The flow characteristics and the method by which the characteristics have been determined are discussed in the next section.

4. WATER FLOW CHARACTERISTICS OF COMPONENTS IN DOMESTIC WATER SYSTEMS

The water flow characteristics of the components of the domestic water supply system must be known if meaningful data is to be obtained from a flow test conducted using a plumbing fixture. The outlet pressure at the test fixture is measured during the course of the flow test. However, for the purpose of calculating the residual pressure at the cross-connection point, the pressure on the system side of the test fixture must be

known. By characterizing the test fixture, the pressure on the system side can be determined from a knowledge of the water flow rate dicharged at the fixture. In addition to the test fixture, other components of the domestic water system which need to be characterized include the piping, valves and fittings.

The test fixture selected for the water flow test can include any water outlet/faucet in a residence, including shower heads, sink spigots, hose bibbs, etc. Unfortunately, all of these devices have not been characterized to determine the pressure-water flow rate relationship for the device. Thus as a part of this study, a set of plumbing faucets, as candidate test fixtures, were selected for characterization.

Outdoor faucets were selected since all houses have at least one outdoor faucet. Further, the spectrum of outdoor faucets was perceived to be less varied than for other types of faucets.

A wide range of outdoor faucets were selected for examination in this study. The specific faucets acquired for examination were selected based on discussions with plumbing supply distributors concerning the market share and availability of a particular type of faucet from a particular manufacturer. The 38 faucets examined included a wide variety of faucets from several manufacturers, including frostproof, anti-siphon and traditional hose bibbs, in addition to lawn faucets and boiler drains, as depicted in Figure 5 [12].

Determination of the hydraulic characteristics of the outdoor faucets was conducted in the Pyrometrics Laboratory at the University of Maryland, using a pressurized water tank. The

measurement equipment for the experiments consisted of a differential manometer and a pressure gage. The differential manometer, used to determine the water flow rate, was connected to a six inch length of 1/2 inch (nominal) diameter steel pipe. The differential manometer was calibrated prior to testing the faucets by correlating the water flow rate to the difference in the elevation levels of the mercury columns. A detailed description of the experimental configuration and calibration procedure is included in a separate report by Dubin and Landmesser [13]. The water flow rate was determined by measuring the time required to fill a calibrated container to a pre-determined volume. Based on the data from the manometer and the pressure gage, a "K" value could be determined assuming a pressure-water flow rate relationship of the form noted in equation (1):

$$Q = K (P)^{0.5}$$

K values for the nozzles tested are noted in Table 7. As indicated in the table, differences in the K values of faucets of the same general type from different manufacturers can be appreciable in some cases. The frostproof hose bibbs have K values ranging from 1.62 to 2.06. Measured K values for anti-siphon fixtures ranged from 1.34 to 1.69. Lawn faucets were determined to have the greatest range, from 1.60 to 2.35. Some of the differences were anticipated due to visually observed variations in the relative roughness of the inside of the faucet. In 10 cases, two fixtures of the same type were tested, in which

case the range and average K values are reported in Table 7. Differences in the measured K value for identical fixtures were less than six percent.

Additional experiments were conducted at the Center for Fire Research including one lawn faucet and one frostproof hose bibb. The K value measured for the lawn faucet ranged from 2.02 to 2.04 in three tests (average of 2.03), whereas the K value for the frostproof ranged from 2.29 to 2.44 in another three tests (average of 2.37) (a complete tabulation of the data collected during the experiments conducted at the Center for Fire Research is included in Appendix A).

The hydraulic characteristics of interest for the piping, valves and fittings are those characteristics that are necessary for the calculation of friction loss through the respective component. Friction loss per unit length is provided in Table 8 for various water flow rates through 1/2", 3/4" and 1" type M copper tube. The friction loss associated with other types of pipe of any diameter, such as types K or L copper tube or PVC pipe, can be determined adjusting the values for 1/2", type M copper tube with the factors also noted in Table 8.

The friction loss for other components, such as valves and fittings is typically addressed through the use of the equivalent length concept. A list of equivalent lengths for tees, elbows and other valves and fittings is included in Table 9.

The only valve not noted in the equivalent length listing in Table 9 is the PRV. The friction loss through a PRV is typically presented in terms of a pressure drop. However, information the

friction loss through a PRV is complicated by the dependence of the friction loss on several variables, including inlet pressure, valve setting, valve size and design. If the valve is opened to its maximum extent, providing the minimum restriction, then the valve setting variable can be eliminated for the purposes of approximating the characteristics of the domestic water system. For the magnitude of inlet pressures typically supplied by a municipal water system, the flow rate associated with selected values of friction loss through 1/2", 3/4" and 1" PRV's from five manufacturers is presented in Table 10 [9-11]. As indicated in the table, the variation in the flow rate for the five valves is appreciable. Average flow rates are included for each size PRV and friction loss value. By formulating a correlation of the flow rate and the average friction loss, the friction loss can be calculated for selected water flow rates and PRV sizes, as included in Table 11.

As a result of the experiments conducted at the Center for Fire Research (see Appendix A), the friction loss through a "typical" PRV was determined. For the three tests in which the friciton loss was measured with the PRV in the "open" position, i.e. with the least constriction to the flow, the friction loss values predicted in Table 11 were within 11 percent of the measured values in all tests (the average error was approximately six percent). This agreement is considered excellent, especially when noting that the measurements were not exact and the correlation was derived as an average friction loss for PRV's from different manufacturers.

5. ANALYSIS OF WATER FLOW TEST RESULTS

The data obtained from conducting a water flow test gives information on the characteristics of the residential water system only at the test point. However, in the context of this project, the characteristics of the domestic water system are desired at the cross-connection point. Thus, an analysis of the data obtained from the water flow test is needed. The subsequent analysis contains two parts. First, the characteristics of the domestic water supply system at the cross-connection point are determined, based on the data obtained from the flow test and by accounting for any sources of pressure change, e.g. friction loss and elevation difference. Second, the residual pressure at the cross-connection point is determined for any water flow rate of interest, e.g. 18 or 26 gpm.

The static pressure at the cross-connection point is based on the static pressure measured during the water flow test and subsequent hydraulic analysis to account for any changes in elevation between the plumbing test fixture and cross-connection point. Specifically, the static pressure at the cross-connection point, PS_{cc}, can be related to the static pressure at the test fixture, PS_{tf}, by the following equation:

$$PS_{cc} = PS_{tf} + 0.433\ y \qquad (2)$$

where:

PS_{cc} : static pressure at cross-connection point (psi)

PS_{tf} : static pressure at test fixture (psi)

y : elevation difference (ft)

The elevation difference, y, is measured from the test point to the cross-connection point. The elevation difference is defined as positive if the cross-connection point is at a lower elevation than the test fixture.

The residual pressure at the cross-connection point can be determined based on the residual pressure at the test point and a hydraulic analysis using data pertaining to the parameters of the residential water system, as presented previously in Section 3.

The hydraulic analysis procedure is outlined in Table 12. As is evident from the length of the table, the procedure involves an appreciable level of detail. The first two steps of the analysis involve recording the characteristics of the domestic water system, including the test fixture, pipe type and length, and number and type of fittings. Step 3 requires the user to enter the water flow rate determined from the flow test. The actual hydraulic analysis is included in steps 4 to 7. The friction loss computation through the pipe and fittings is performed in step 4. Pressure losses through the PRV is addressed in step 5. The effect of elevation is addressed in step 6. The cumulative effects of the three sources of pressure change are summed in step 7.

Using the results of the hydraulic analysis procedure, the domestic water supply system can be completely characterized, such that the residual pressure at the cross-connection point can be determined for any flow rate using equation (3):

$$Q_2/Q_1 = (PD_2/PD_1)^{0.54} \qquad (3)$$

where:

Q_1 : measured flow rate during flow test (gpm)

Q_2 : flow rate of interest (gpm)

PD_1 : pressure drop with a flow rate of Q_1 (psi)

PD_2 : pressure drop with a flow rate of Q_2 (psi)

Q_1 and PD_1 are the water flow rate and pressure drop respectively, as acquired in a flow test and converted to the cross-connection point via the hydraulic analysis. The pressure drop is defined as the difference between the static pressure and residual pressure [4]. Q_2 and PD_2 are the water flow rate and pressure drop associated with a desired water flow rate, e.g. 18 or 26 gpm as required for a residential fire sprinkler system. Included in Table 13 are values of $PD^{0.54}$ for pressure drops from 1 to 100 psi.

Equation (3) can be applied using the values obtained as a result of the hydraulic analysis of the flow test data, to assess the adequacy of the municipal water supply system by determining if there is adequate pressure for a residential sprinkler system requiring a water flow rate of 18 or 26 gpm. Equation (3) can be rewritten to solve for PD_2:

$$PD_2 = PD_1 \ (Q_2/Q_1)^{1.85} \qquad (4)$$

Values of the ratio of water flow rates, Q_2/Q_1, are presented in Table 14 for selected values of Q_1, with Q_2 set equal to either 18 or 26 gpm.

Equation (4) can be modified to include the respective static and residual pressure instead of the pressure drop, since the pressure drop is the difference between the static and residual pressures.

$$P_s - P_{r2} = (P_s - P_{r1})\ (Q_2/Q_1)^{1.85} \qquad (5)$$

where:

P_s : static pressure (psi)

P_{r1} : residual pressure with a flow rate of Q_1 (psi)

P_{r2} : residual pressure with a flow rate of Q_2 (psi)

P_{r1} can be interpretted as the calculated residual pressure at the cross-connection point (determined from the water flow test at the test fixture and subsequent hydraulic analysis). P_{r2} is given as the demand residual pressure at the cross-connection point associated with the demand water flow rate, Q_2, (either 18 or 26 gpm) (from the procedure outlined in Table 2). Solving for P_{r2} will provide an equation for the demand residual pressure at the cross-connection point, given the results from the analysis of the water flow test (P_s, P_{r1} and Q_1):

$$P_{r2} = P_s\ [1 - (Q_2/Q_1)^{1.85}] + P_{r1}(Q_2/Q_1)^{1.85} \qquad (6)$$

Equation (6), in addition to equation (3) can be useful in interpretting flow test results. Specifically, equation (3) can be used to determine the water flow rate available at a desired pressure, P_{r2}, given P_s, P_{r1} and Q_1 determined from the flow test and subsequent analysis. The equation may also be applied to determine the maximum flow available by setting P_{r2} equal to

zero. As an example, consider the following values are obtained from conducting a water flow test and subesequent analysis (to relate pressures measured at the test fixture to the cross-connection point):

a. water flow rate = 10 gpm

b. residual pressure = 60 psi

c. static pressure = 70 psi

From equation (3), the maximum flow available is 28.6 gpm. Thus, the domestic water system is capable of supplying 26 gpm. Equation (6) can be applied to determine the residual pressure available at a desired flow rate, e.g. 26 gpm. For this case, the residual pressure at 26 gpm is determined as 11.4 psi. A residual pressure of only 11.4 psi is not sufficient to supply a residential sprinkler system. Thus, these results would indicate that the necessary water flow rate is available, though not at the required pressure, thereby suggesting that a pump will be needed to supplement a deficient water supply.

6. DETERMINATION OF THE ADEQUACY OF THE MUNICIPAL WATER SUPPLY

A total of 22 residences were selected at random in the Baltimore, Maryland - Washington, D.C. metropolitan area for examination of the water supply characteristics of the domestic water system. The primary purpose of the site visits to the selected residences was to obtain information on the parameters of domestic water systems within the residences, such as diameter, length and type of pipe, number and type of valves and fittings, elevation, type of test fixtures, etc. The observed

values of the parameters of the domestic cold water system in the 22 residences necessary for the hydraulic analysis are noted in Table 15. Based on the survey of residences in the Baltimore, Maryland - Washington, D.C. metropolitan area, a range of values were noted for each of the domestic water system variables which would affect the hydraulics of the domestic water system. Specifically, 1/2 inch (nominal) copper tube was generally used for the piping between the hose bibb, or other plumbing fixture used in the flow test, and the main water supply riser, which was typically 3/4" copper tube. The length of piping between the test and cross-connection points ranged from five to 50 feet. Generally, the elevation change between the outlet and a potential cross-connection point was not greater than five feet.

In addition, the water flow tests were performed to determine the characteristics (static pressure, residual pressure and water flow rate) of the municipal water supply within the residences. Measurements obtained from the 22 water flow tests at the selected residences (static pressure and water flow rate) are presented in Table 16.

The hydraulic analysis outlined in Table 12 was conducted for each of the selected residences to determine the friction loss and any pressure gain or loss due to elevation changes between the test point and cross-connection point. A roughness coefficient of 140 was assumed for the copper tube and 150 for the PVC pipe. Equivalent lengths of pipe were considered for any fittings, previously provided in Table 9. The results of the hydraulic analyses for the selected residences are also presented

in Table 16. The maximum water flow rate capable of being delivered by the domestic water system system (at a residual pressure of 0 psi) is also provided in the table.

7. ASSESSMENT OF THE ADEQUACY OF THE MUNICIPAL WATER SUPPLY BY HOMEOWNERS

Adequacy of the municipal water supply can be determined using a four step procedure, as previously alluded to. First, the demand requirements posed by a residential sprinkler system must be calculated. Second, the characteristics of the residential cold water system need to be determined. The next step consists of conducting a water flow test. Finally, an analysis of the flow test measurements is performed.

Three approaches have been presented in Section 2 of this report to complete the first step of the analysis involving the determination of the water demand requirements for the residential sprinkler system. The demand requirements posed by a residential sprinkler system can be assessed by conducting a detailed hydraulic analysis, such as the procedure documented by Clark and Coutts [3], or by using either of the two simplified procedures outlined in Tables 2 and 4. The elementary method outlined in Table 4 should be a reasonable exercise for interested homeowners, involving at most 12 steps, requiring elementary mathematical operations and requiring input which is readily acquired.

As previously noted in Section 2 of this report, the demand requirements may need to be stated in terms of a demand pressure

at both 18 and 26 gpm. For sprinkler system designs using 3/4 inch pipe, then only the single demand pressure at 26 gpm is needed to fully state the demand requirements. The single demand pressure at 26 gpm is sufficient to completely state the demand requirements since the demand pressure at 26 gpm is greater than the demand pressure at 18 gpm. However, two demand pressures (at 18 and 26 gpm) must be determined for sprinkler system designs using 1 inch pipe to properly identify the demand requirements since the demand pressure at 18 gpm is greater than the demand pressure at 26 gpm.

As the second step of the analysis, the characteristics of the residential cold water system are relatively easy to obtain if all of the piping, fittings, and valves are exposed. The type of copper tube can be determined by the color of the lettering on the tube. Type K copper tube is identified by green lettering, type L by blue lettering and type M by red lettering. The diameter of the pipe can be determined by measuring the outside diameter of the pipe. The outer pipe diameters typically used in residential water systems are related to the nominal pipe diameters in Table 6.

The procedure for conducting the water flow test noted as the third step of the analysis is elementary. However, the needed measurement apparatus may not be readily available to determine the static and residual pressure, as well as the water flow rate. The measurement device used by lawn sprinkler companies, referred to in Section 3.2 of this report and depicted in Figure 2, could be acquired through a lease or purchase

arrangement. The purchase price of the measurement apparatus is reported as being approximately $60. Even with a widely expanded market beyond lawn sprinkler contractors for the apparatus, it does not appear likely that the cost of the apparatus would be reduced to a level that would be considered acceptable for purchase by most homeowners. As an alternative, perhaps leasing arrangements could become available for the measurement device. Fire departments that wish to encourage the retrofitting of residential sprinkler systems could purchase a limited number of the flow measurement apparatus, or may have a similar flow test measurement device, for use by fire fighters (to assist the homeowner) or on a check-out basis for use by the individual homeowners.

Alternatively, instead of using the flow apparatus, a homeowner could acquire a Bourdon pressure gage to measure the static pressure, either by purchasing such a gage or by leasing or borrowing one as described for the flow measurement apparatus. The water flow rate can be determined by measuring the quantity (volume) of water discharged during a known period of time. The volume of water discharged can be measured by using a calibrated container or by using the residential water meter. The water flow rate is determined as the ratio of the water flow quantity discharged to the duration of the flow discharge.

The final step, consisting of the hydraulic analysis of the residential cold water system, can be conducted using one of three procedures. The accuracy of the results is directly related to the complexity of the procedure.

The approach outlined in Table 12 can be used, requiring an appreciable level of effort and yielding the most accurate answer. A principal reason for the length of the procedure is the need to account for the effects of the various fittings (elbows and tees) in a domestic water system. Consequently, all of the fittings between the test fixture and the cross-connection point must be identified. If all of the pipe and fittings are exposed, then the necessary information can be readily acquired. Conversely, this information may be not be readily obtained if the pipe is concealed in the walls, above a ceiling, or below a floor slab. Without all of the needed information, the detailed approach outlined in Table 12 cannot be used.

As an alternative, the simplified calculation procedure presented in Table 17 can be applied. Input requirements for this approach are not as extensive as in Table 12 and the method is less complex. However, some accuracy is lost due to the fact that the fittings are not explicitly accounted for. The principal simplification in the procedure included in Table 17, as compared to that in Table 12, involves considering the effect of the fittings by increasing the pipe length by a factor of 50 percent.

The procedure, outlined in Table 17, includes the following basic steps. First, the homeowner compares the faucet type used as the test fixture with those illustrated in Figure 5 in order to determine a "K" factor for the fixture. If the homeowner is unable to find a comparable fixture in Figure 5 with that used as

the test fixture, a "K" value of 2 may be used (as the nominal average K value for all fixtures).

It should be noted that when using the flow apparatus illustrated in Figure 2, an effective K factor for the combination of the nozzle and flow apparatus must be known in order to interpret any data acquired. The K value for the flow apparatus was extracted from the data acquired from the experiments conducted at the Center for Fire Research. The calculated K value in four tests with the flow apparatus averaged 2.31, ranging from 2.17 to 2.40 (the range in the K value is indicative of the errors inherent in water flow tests). An effective K can be determined as follows:

$$(1/K_{eff})^2 = (1/K_{tf})^2 + (1/K_{fa})^2 \qquad (7)$$

where:

K_{eff} : effective K factor for test fixture and flow apparatus

K_{tf} : K factor for test fixture

K_{fa} : K factor for flow measurement apparatus

Considering a K_{tf} for the average test fixture of 2.0 and K_{fa} of 2.3 for the flow apparatus, the effective K factor, K_{eff}, determined by equation (7) is 1.5.

Finally, the homeowner estimates the length of pipe between the test fixture and a potential cross-connection point (it is assumed that the same pipe size is used for the entire length).

Having made the noted observations, the next task for the homeowner consists of conducting a water flow test. The water flow rate may be determined by using the flow measurement device,

illustrated in Figure 2, or by measuring the time required to fill a container of a known volume. Alternatively, the water meter in the residence may be used to record the volume of water discharged. The static pressure can be determined by using a pressure gage attached to the same faucet used in the flow test or by contacting the water authority for the static pressure obtained during a flow test performed at the fire hydrant closest to the residence (and correcting for any elevation change).

Upon completion of the flow test, acquiring the water flow rate and static pressure, and having noted the characteristics of the domestic water system, Table 17 can be completed. The output of the method outlined in Table 17 includes the static and residual pressures at the cross-connection point at the water flow rate measured during the flow test. In addition, the maximum available water flow rate is determined (at 0 psi residual pressure). The residual pressure at the cross-connection point for the demand water flow rate of 18 gpm (1 inch sprinkler system designs) is calculated, as long as the maximum available water flow rate is at least 18 gpm. Similarly, the residual pressure at the cross-connection point for the demand water flow rate of 26 gpm (3/4 and 1 inch sprinkler system designs) is calculated, as long as the maximum available water flow rate is at least 26 gpm. The results of applying the simplified analysis method for the 22 residences are included in Table 16.

Next, the homeowner determines the adequacy of the domestic water supply system. This can be accomplished by comparing the

demand residual pressure with the available residual pressure at 26 gpm for 3/4 inch sprinkler system designs or at both 18 and 26 gpm for 1 inch sprinkler system designs. If the demand pressure is less than the available pressure at the applicable demand water flow rate(s), then the domestic water system is capable of adequately supplying a residential sprinkler system. Conversely, if the demand residual pressure is greater than the available residual pressure (at either or both water flow rates for the case of 1 inch sprinkler system designs), then the domestic water system is inadequate.

It should be noted that the methods outlined in Tables 12 and 17 are subject to error. Each includes a series of approximations, ranging from characterization of the test fixtures and PRV's, pipe roughness being accurately addressed by the noted "C" values, fittings being included implicitly by a factor, etc. In addition, as with any water flow test, the results are subject to change if the test is repeated during a different time of the day or year, as the characteristics of the water supply within a municipal water distribution system are not static. If the available and demand residual pressures are approximately equal, the adequacy or inadequacy of the domestic water system cannot be assessed definitively.

8. SUMMARY

This report has documented two analysis methods with different levels of complexity and accuracy for determining the adequacy of the domestic water system for supplying a residential sprinkler

system. As a part of the input data requirements for the two approaches, the hydraulic characteristics of domestic water systems, including plumbing faucets and PRV's had to be determined. Selected hose faucets were experimentally characterized. The friction loss characteristics of PRV's were analyzed based on information extracted from the literature of three different manufacturers for five valves commonly used in residences.

Outlines of the relatively easy-to-use analysis approaches were provided for homeowners to use in assessing the adequacy of the domestic water system. Use of the simplified approaches requires little technical expertise. The amount of effort required to conduct the analysis has been minimized through the application of simplifying assumptions of the outlined methods. In applying the analysis technique to the 22 residences surveyed, the domestic water supply systems were able to provide maximum water flow rates between 36.2 and 87.3 gpm.

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Table 1: Water Demand Requirements (PSI)
Cross-Connection Point [1]

Residence	3/4 inch CPVC Pipe: One Operating Sprinkler	3/4 inch CPVC Pipe: Two Operating Sprinklers	1 inch CPVC Pipe: One Operating Sprinkler	1 inch CPVC Pipe: Two Operating Sprinklers
Ranch-3 Bedroom (Style 1)	32.1	28.7	27.3	19.2
Ranch-3 Bedroom (Style 2)	40.8	38.9	30.7	23.1
Colonial-3 Bedroom	44.2	47.8	36.6	32.5
Colonial-5 Bedroom	45.4	44.4	34.7	27.7
Townhouse-2 Bedroom	38.2	43.0	31.7	27.2
Townhouse-3 Bedroom	43.4	49.4	35.8	31.6
Split Level-3 Bedroom	38.1	34.0	31.5	23.5

Table 2. Simplified Procedure to Estimate the Demand Requirements of a Residential Sprinkler System

1. Identify the location where the water line enters the dwelling

2. Enter the distance, A (in feet)(see Figure 1) ________

   ("A" is the horizontal distance from the entrance point of the water line to walls 1 or 2, whichever is most distant)

3. Enter the distance, B (in feet)(see Figure 1) ________

   ("B" is the horizontal distance from the entrance point of the water line to walls 3 or 4, whichever is most distant)

4. Enter the distance, C (in feet)(see Figure 1) ________

   ("C" is the vertical distance from the entrance point of the water line to the ceiling of the top level of the residence)

5. Add lines 2, 3, and 4 ________

6. Select type of pipe

Copper, Type M (3/4 inch)	X = 0.557	Y = 0.282
Copper, Type M (1 inch)	X = 0.155	Y = 0.079
Polybutylene (PB) (3/4 inch)	X = 0.368	Y = 0.186
Polybutylene (PB) (1 inch)	X = 0.123	Y = 0.062
CPVC (3/4 inch)	X = 0.322	Y = 0.163
CPVC (1 inch)	X = 0.107	Y = 0.054

   (For pipe type other than noted above, obtain "X" and "Y" friction loss per foot, from pipe distributor)

   Enter value of "X" for pipe type selected ________

   Enter value of "Y" for pipe type selected ________

7. Multiply Line 5 by X from Line 6 ________

8. Multiply Line 4 by 0.433 ________

9. Add Line 7 and Line 8 ________

10. Multiply Line 5 by Y from Line 6 ________

11. Add line 8 and Line 10 ________

** Demand Requirements: 26 gpm at _______ psi (from Line 9) **
** **
** Demand Requirements: 18 gpm at _______ psi (from Line 11) **

Table 3. Comparison of Estimated and Hydraulically Calculated Demand Requirements for a Residential Sprinkler System

3/4" CPVC Pipe

House Style

	Ranch 3 Bedroom Style 1	Ranch 3 Bedroom Style 2	Colonial 3 Bedroom	Colonial 5 Bedroom	Townhouse 2 Bedroom	Townhouse 3 Bedroom	Split Level 3 Bedroom
Line 2	29.4	36.9	21.2	31.1	27.8	25.0	23.2
Line 3	30.8	26.3	16.4	16.3	26.6	26.4	10.9
Line 4	11.0	11.0	27.0	20.9	19.0	27.0	19.0
Line 5	71.2	74.2	64.6	68.3	73.4	78.4	53.1
Line 6	0.322	0.322	0.322	0.322	0.322	0.322	0.322
Line 7	22.9	23.9	20.8	22.0	23.6	25.2	17.1
Line 8	4.8	4.8	11.7	9.0	8.2	11.7	8.2
Line 9	39.1	40.1	43.9	42.4	43.3	48.3	36.7
Calculated Residual Pressure	28.7	38.9	47.8	44.4	43.0	49.4	34.0

1" CPVC Pipe

House Style

	Ranch 3 Bedroom Style 1	Ranch 3 Bedroom Style 2	Colonial 3 Bedroom	Colonial 5 Bedroom	Townhouse 2 Bedroom	Townhouse 3 Bedroom	Split Level 3 Bedroom
Line 2	29.4	36.9	21.2	31.1	27.8	25.0	23.2
Line 3	30.8	26.3	16.4	16.3	26.6	26.4	10.9
Line 4	11.0	11.0	27.0	20.9	19.0	27.0	19.0
Line 5	71.2	74.2	64.6	68.3	73.4	78.4	53.1
Line 6	0.107	0.107	0.107	0.107	0.107	0.107	0.107
Line 7	7.6	7.9	6.9	7.3	7.9	8.4	5.7
Line 8	4.8	4.8	11.7	9.0	8.2	11.7	8.2
Line 9	23.8	24.1	30.0	27.8	27.5	31.5	25.3
Calculated Residual Pressure	19.2	23.1	32.5	27.7	27.2	31.6	23.5

Table 3. Comparison of Estimated and Hydraulically Calculated Demand Requirements for a Residential Sprinkler System (Cont'd)

3/4" CPVC Pipe — House Style

	Ranch 3 Bedroom Style 1	Ranch 3 Bedroom Style 2	Colonial 3 Bedroom	Colonial 5 Bedroom	Townhouse 2 Bedroom	Townhouse 3 Bedroom	Split Level 3 Bedroom
Line 2	29.4	36.9	21.2	31.1	27.8	25.0	23.2
Line 3	30.8	26.3	16.4	16.3	26.6	26.4	10.9
Line 4	11.0	11.0	27.0	20.9	19.0	27.0	19.0
Line 5	71.2	74.2	64.6	68.3	73.4	78.4	53.1
Line 6	0.163	0.163	0.163	0.163	0.163	0.163	0.163
Line 7	11.6	12.1	10.5	11.1	12.0	12.8	8.7
Line 8	4.8	4.8	11.7	9.0	8.2	11.7	8.2
Line 9	38.3	38.8	44.1	42.1	42.1	46.4	38.8
Calculated Residual Pressure	32.1	40.8	44.2	45.4	38.2	43.4	38.1

1" CPVC Pipe — House Style

	Ranch 3 Bedroom Style 1	Ranch 3 Bedroom Style 2	Colonial 3 Bedroom	Colonial 5 Bedroom	Townhouse 2 Bedroom	Townhouse 3 Bedroom	Split Level 3 Bedroom
Line 2	29.4	36.9	21.2	31.1	27.8	25.0	23.2
Line 3	30.8	26.3	16.4	16.3	26.6	26.4	10.9
Line 4	11.0	11.0	27.0	20.9	19.0	27.0	19.0
Line 5	71.2	74.2	64.6	68.3	73.4	78.4	53.1
Line 6	0.054	0.054	0.054	0.054	0.054	0.054	0.054
Line 7	3.8	4.0	3.5	3.7	4.0	4.2	2.9
Line 8	4.8	4.8	11.7	9.0	8.2	11.7	8.2
Line 9	30.5	30.7	37.1	34.6	34.1	37.8	33.0
Calculated Residual Pressure	27.3	30.7	36.6	34.7	31.7	35.8	31.5

Table 4. Elementary Procedure to Determine the Demand Pressure

1. Select type of pipe

Copper, Type M (3/4 inch)	A = 43.0
Copper, Type M (1 inch)	A = 12.2
Polybutylene (PB) (3/4 inch)	A = 28.0
Polybutylene (PB) (1 inch)	A = 9.5
CPVC (3/4 inch)	A = 25.0
CPVC (1 inch)	A = 8.4

(For a pipe type other than noted above, obtain "X" and "Y" (friction loss per foot) from pipe distributor)

Enter value of "X" for pipe type selected ________

Enter value of "Y" for pipe type selected (1" pipe only) ________

2. Enter elevation change, in feet ________

(The elevation change is the vertical distance from the entrance point of the water line to the ceiling of the top level of the residence)

3. Multiply Line 2 by 0.43 ________

4. 3/4" pipe calculation

4.1 Sprinkler Orifice Pressure 11.4

4.2 Friction Loss: Enter A from Line 1 ________

4.3 Enter elevation change, from Line 3 ________

4.4 Add Lines 4.1, 4.2, and 4.3 ________

** Proceed to Line 7 **

5. 1" pipe calculation, one operating sprinkler

5.1 Sprinkler Orifice Pressure 21.9

5.2 Friction Loss: Enter A from Line 1 ________

5.3 Divide Line 5.2 by 2 ________

5.4 Enter elevation change, from Line 3 ________

5.5 Add Lines 5.1, 5.3, and 5.4 ________

6. 1" pipe calculation, two operating sprinklers

6.1 Sprinkler Orifice Pressure 11.4____

6.2 Friction Loss: Enter A from Line 1 ________

6.3 Enter elevation change, from Line 3 ________

6.4 Add Lines 6.1, 6.2, and 6.3 ________

7. Summary

Demand Requirements: 26 gpm at _______ psi (from Line 4.4 or 6.4)

Demand Requirements: 18 gpm at _______ psi (from Line 5.5)

Table 5. Comparison of Calculated Demand Pressures

3/4 inch CPVC
2 operating sprinklers

	House Style						
	Ranch [3 Bedroom] Style 1	Ranch [3 Bedroom] Style 2	Colonial [3 Bedroom]	Colonial [5 Bedroom]	Townhouse [2 Bedroom]	Townhouse [3 Bedroom]	Split Level [3 Bedroom]
Hydraulically Calculated	28.7	38.9	47.8	44.4	43	49.4	34
Simplified Procedure (Table 2)	39.1	40.1	43.9	42.4	43.3	48.3	36.7
Elementary Procedure (Table 4)	41.2	41.2	48.1	45.4	44.6	48.1	44.6

1" CPVC Pipe
1 operating sprinkler

	House Style						
	Ranch [3 Bedroom] Style 1	Ranch [3 Bedroom] Style 2	Colonial [3 Bedroom]	Colonial [5 Bedroom]	Townhouse [2 Bedroom]	Townhouse [3 Bedroom]	Split Level [3 Bedroom]
Hydraulically Calculated	27.3	30.7	36.6	34.7	31.7	35.8	31.5
Simplified Procedure (Table 2)	30.5	30.7	37.1	34.6	34.1	37.8	33.0
Elementary Procedure (Table 4)	30.9	30.9	37.8	35.1	34.3	37.8	34.3

1" CPVC Pipe
2 operating sprinklers

	House Style						
	Ranch [3 Bedroom] Style 1	Ranch [3 Bedroom] Style 2	Colonial [3 Bedroom]	Colonial [5 Bedroom]	Townhouse [2 Bedroom]	Townhouse [3 Bedroom]	Split Level [3 Bedroom]
Hydraulically Calculated	19.2	23.1	32.5	27.7	27.2	31.6	23.5
Simplified Procedure (Table 2)	23.8	24.1	30.0	27.8	27.5	31.5	25.3
Elementary Procedure (Table 4)	24.6	24.6	31.5	28.8	28	31.5	28

Table 6. Internal and External Diameters for Typical Pipe Sizes Used in Residential Water Systems [5-8]

Internal Diameter

Pipe Type	1/2"	3/4"	1"
Copper			
Type K	0.527	0.745	.995
Type L	0.545	0.785	1.025
Type M	0.569	0.811	1.055
PVC, Schedule 40	0.622	0.824	1.049

External Diameter

Pipe Type	1/2"	3/4"	1"
Copper			
Type K	0.625	0.875	1.125
Type L	0.625	0.875	1.125
Type M	0.625	0.875	1.125
PVC, Schedule 40	0.840	1.050	1.315

Table 7. K Values of Examined Plumbing Fixtures

Fixture Type	Manufacturer A	B	C	D	E	F	Average All Manufacturers
Frostproof							
4"	-	-	-	1.70	-	-	1.70
6"	-	1.81-1.88 (1.84)	2.01-2.02 (2.01)	1.99	-	-	2.01
8"	-	-	1.93-1.95 (1.94)	2.06	-	-	1.93
10"	1.67	-	1.99-2.10 (2.05)	2.04	-	-	1.95
12"	1.62	1.74-1.77 (1.75)	-	1.91	-	-	1.76
14"	-	-	-	1.98	-	-	1.98
Average (All Frostproof)							1.90
Anti-Siphon/Frostproof							
4"	-	-	1.34	-	-	-	1.34
6"	-	-	1.48	-	-	1.59	1.53
8"	-	-	1.34-1.37 (1.35)	-	-	-	1.35
12"	-	-	-	-	-	1.59	1.59
Lawn Faucet	1.69	-	-	-	-	-	1.69
Boiler Drain	1.69	-	-	-	-	-	1.69
Average (All Anti-Siphon Frostproof)							1.51

Fixture Type	Manufacturer A	B	C	D	E	F	Average All Manufacturers
Anti-Siphon/Non-Frostproof							
Lawn Faucet	1.57	-	-	-	-	-	1.57
Other							
Lawn Faucet	2.18-2.30 (2.24)	1.78-1.81 (1.79)	-	-	-	1.60	1.93
Hose Bibb	-	1.64-1.74 (1.69)	-	-	-	1.48-1.54 (1.51)	1.60
Boiler Drain	2.32	-	-	-	2.15	-	2.23
Average (All Other)							1.87

Table 8: Friction Loss Factors for Pipe Commonly Used in Domestic Cold Water Systems

Friction Factor for 1/2" Copper, Type M

Water Flow Rate (gpm)	Factor (psi/ft)	Water Flow Rate (gpm)	Factor (psi/ft)
1.0	0.0075	10.0	0.534
1.5	0.0160	11.0	0.637
2.0	0.0272	12.0	0.748
2.5	0.0411	13.0	0.867
3.0	0.0576	14.0	0.995
3.5	0.0765	15.0	1.130
4.0	0.0980	16.0	1.274
4.5	0.122	17.0	1.425
5.0	0.148	18.0	1.584
5.5	0.177	19.0	1.750
6.0	0.207	20.0	1.924
6.5	0.241	21.0	2.106
7.0	0.276	22.0	1.924
7.5	0.314	23.0	2.492
8.0	0.353	24.0	2.969
8.5	0.395	25.0	2.908
9.0	0.439	26.0	3.127
9.5	0.486		

Adjustment Factors for Other Pipe Material, Type or Diameter

Pipe Material/Type	Nominal Pipe Diameter (inches)		
	1/2	3/4	1
Copper/ Type K	1.45	.269	.0658
Copper/ Type L	1.23	.209	.0569
Copper/ Type M	1.00	.178	.0494
PVC/ Schedule 40	.570	.145	.0447

Table 9: Equivalent Length of Pipe for Valves and Fittings [6]

Fitting Size Inches	Equivalent Length of Pipe, feet						
	Standard Ells		90 Tees		Coupling	Gate Valve	Globe Valve
	90	45	Branch	Run			
3/8	0.5	0.5	1.0	0.5	0.5	0.5	4.0
1/2	1.0	1.0	1.5	0.5	0.5	0.5	7.5
3/4	1.0	1.0	2.0	0.5	0.5	0.5	10
1	2.0	1.0	2.0	0.5	0.5	0.5	12
1 1/4	2.0	1.0	3.0	1.0	1.0	0.5	18
1 1/2	2.5	1.5	3.5	1.0	1.0	0.5	23
2	3.5	2.0	5.0	1.0	1.0	1.0	28
2 1/2	4.0	2.5	6.0	1.5	1.5	1.0	33
3	5.0	3.0	7.5	1.5	1.5	1.0	40
3 1/2	6.0	3.5	9.0	2.0	2.0	1.0	50
4	7.0	4.0	10.5	2.0	2.0	1.5	63
5	9.0	5.0	13.0	2.5	2.5	1.5	70
6	10.0	6.0	15.0	3.0	3.0	2.0	84

Table 10. Relationship of Water Flow Rate and Friction Loss for Residential PRV's [9-11]

PRV size: 1/2"

Pressure Drop (psi)	PRV Model A	B	C	D	E	Average
5	2.5	3.0	4.0	3.5	4.0	3.4
10	5.0	6.0	5.5	4.0	8.0	5.7
15	6.5	8.0	7.5	4.5	9.6	7.2
20	7.5	9.5	9.5	5.0	13.6	9.0

PRV size: 3/4"

Pressure Drop (psi)	PRV Model A	B	C	D	E	Average
5	3.5	4.0	5.0	7.8	4.8	5.2
10	7.0	8.5	6.5	9.0	10.4	8.1
15	9.5	12.5	8.0	10.0	16.8	11.4
20	10.5	15.5	9.5	11.2	21.6	13.7

PRV size: 1"

Pressure Drop (psi)	PRV Model A	B	C	D	E	Average
5	6.0	7.0	8.5	14.0	5.6	8.2
10	11.5	15.0	11.5	16.0	16.0	13.9
15	15.5	22.0	13.0	18.0	24.0	18.5
20	19.0	28.0	14.5	20.0	32.0	22.7

Table 11. Pressure Drop through Residential PRV's

Water Flow Rate (gpm)	Pressure Drop (psi) 1/2"	3/4"	1"
1	6.1	4.7	3.6
2	10.0	7.6	5.7
3	13.4	10.1	7.4
4	16.4	12.4	9.0
5	19.3	14.5	10.5
6	21.9	16.5	11.8
7	24.4	18.4	13.1
8	26.9	20.1	14.3
9	29.2	21.9	15.5
10	31.5	23.6	16.7
12	35.8	26.8	18.8
14	40.0	29.8	20.9
16	44.0	32.7	22.9
20	51.5	38.3	26.5
22	55.1	40.9	28.2
24	58.6	43.5	29.9
26	62.1	46.0	31.6

Table 12. Procedure to Estimate the Characteristics of the Municipal Water Supply

1. Determine K value for hose faucet ________

   (see Figure 5: identify faucet that most closely resembles faucet used in test)

2. Determine water piping characteristics between faucet and water meter.

   2.1 1/2 inch diameter pipe

      2.1.1 Length of 1/2 inch pipe ________ft

      2.1.2 Number of elbows (45 or 90^{o}) ________

      2.1.3 Multiply 2.1.2 by factor from Table 9 ________

      2.1.4 Number of tees ________

      2.1.5 Multiply 2.1.4 by factor from Table 9 ________

      2.1.6 Add 2.1.1, 2.1.3 and 2.1.5 ________ft

   2.2 3/4 inch diameter pipe (skip to Line 2.3 if none)

      2.2.1 Length of 3/4 inch pipe ________ft

      2.2.2 Number of elbows (45 or 90^{o}) ________

      2.2.3 Multiply 2.2.2 by factor from Table 9 ________

      2.2.4 Number of tees ________

      2.2.5 Multiply 2.2.4 by factor from Table 9 ________

      2.2.6 Add 2.2.1, 2.2.3 and 2.2.5 ________ft

   2.3 1 inch diameter pipe (skip to Line 3 if none)

      2.3.1 Length of 1 inch pipe ________ft

      2.3.2 Number of elbows (45 or 90^{o}) ________

      2.3.3 Multiply 2.3.2 by factor from Table 9 ________

      2.3.4 Number of tees ________

2.3.5 Multiply 2.3.4 by factor
from Table 9 _______

2.3.6 Add 2.3.1, 2.3.3 and 2.3.5 _______ft

3. Flow water: Open faucet and return to meter. Determine amount of water flowed in 5 minute interval. (Note: make sure that no water is flowed from any other outlet in residence during the 5 minute test interval)

3.1 Enter total flow in gallons _______gal

3.2 Divide Line 3.1 by 5 _______gpm

3.3 Divide Line 3.2 by Line 1. _______

3.4 Multiply Line 3.3 by Line 3.3 (square line 3.3) _______

4. Friction loss calculation

4.1 1/2 inch pipe

4.1.1 Enter friction factor from Table 8 for type of pipe and water flow rate entered on Line 3.2 _________psi/ft

4.1.2 Multiply Line 4.1.1 by Line 2.1.6 _________psi

4.2 3/4 inch pipe

4.2.1 Enter friction factor from Table 8 for type of pipe and water flow rate entered on Line 3.2 _________psi/ft

4.2.2 Multiply Line 4.2.1 by Line 2.2.6 _________psi

4.3 1 inch pipe

4.3.1 Enter friction factor from Table 8 for type of pipe and water flow rate entered on Line 3.2 _________psi/ft

4.3.2 Multiply Line 4.3.1 by Line 2.3.6 _________psi

4.4 Add Line 4.1.2, Line 4.2.2 and Line 4.3.2 _______psi

5. If a pressure reducing valve is present, enter friction loss from Table 11, for water flow rate entered in Line 3.2, otherwise enter 0. (see Figure 4 for sketches of typical pressure reducing valves) _______psi

6. Determine pressure change due to elevation

6.1 Enter difference in elevation from faucet to meter in feet (if faucet is higher than meter, enter elevation change as positive value; if faucet is lower than meter, enter elevation change as negative value) ________ft

6.2 Multiply Line 5 by 0.433 ________psi

7. Add Lines 3.4, 4.4, 5 and 6.2 ________psi

8. Determine Static Pressure

8.1 Attach pressure gauge to faucet.

8.2 Open faucet, record pressure ________psi

8.3 Add Line 8.2 and 6.2 _______psi

9. Calculate maximum available flow rate

9.1 Calculate pressure drop (PD) for measured water flow rate: Subtract Line 7 from Line 8.3 _______psi

9.2 Using Table 13, determine factor for PD noted on Line 9.1 _______

9.3 Using Table 13, determine factor associated with static pressure, entered on Line 8.3 _______

9.4 Multiply Line 3.2 by Line 9.3 _______

9.5 Divide Line 9.4 by Line 9.2 _______gpm

** If water flow rate on Line 9.5 is at least **
** 26 gpm proceed to Line 10. Otherwise, continue **
** to summary on Line 12. **

10. Calculate residual pressure at 26 gpm. (complete for proposed sprinkler system designs containing 3/4 and 1 inch pipe)

10.1 Using Table 14, determine flow factor for water flow rate entered on Line 3.2 _______

10.2 Subtract Line 7 from Line 8.3 _______psi

10.3 Multiply Line 10.1 by Line 10.2 _______psi

10.4 Subtract Line 10.3 from Line 8.3 _______psi

11. Calculate residual pressure at 18 gpm. (only complete for proposed sprinkler system designs containing 1 inch pipe)

11.1 Divide Line 10.1 by 1.97 (flow factor for 18 gpm) _______

11.2 Multiply Line 11.1 by Line 10.2 _______psi

11.3 Subtract Line 11.2 from Line 8.3 _______psi

12. Summary

****

Available water supply is given as follows:

Static Pressure : ________ psi (from Line 8.3)

Residual Pressure : ________ psi (from Line 7)

________ gpm (from Line 3.2)

Maximum Available Water Flow Rate ________ (from Line 9.5)

Residual Pressure @ 18 gpm ________ psi (from Line 11.3)

Residual Pressure @ 26 gpm ________ psi (from Line 10.4)

****

Table 13: Pressure Drop Factors for Equation (3)

PD	K	PD	K	PD	K	PD	K
1	1.00	26	5.81	51	8.36	76	10.37
2	1.45	27	5.93	52	8.44	77	10.44
3	1.81	28	6.05	53	8.53	78	10.51
4	2.11	29	6.16	54	8.64	79	10.59
5	2.39	30	6.28	55	8.71	80	10.66
6	2.63	31	6.39	56	8.79	81	10.73
7	2.86	32	6.5	57	8.88	82	10.80
8	3.07	33	6.61	58	8.96	83	10.87
9	3.28	34	6.71	59	9.04	84	10.94
10	3.47	35	6.82	60	9.12	85	11.01
11	3.65	36	6.93	61	9.21	86	11.08
12	3.83	37	7.03	62	9.29	87	11.15
13	4.00	38	7.13	63	9.37	88	11.22
14	4.16	39	7.23	64	9.45	89	11.29
15	4.32	40	7.33	65	9.53	90	11.36
16	4.48	41	7.43	66	9.61	91	11.43
17	4.62	42	7.53	67	9.69	92	11.49
18	4.76	43	7.62	68	9.76	93	11.56
19	4.90	44	7.72	69	9.84	94	11.63
20	5.04	45	7.81	70	9.92	95	11.69
21	5.18	46	7.91	71	9.99	96	11.76
22	5.31	47	8.00	72	10.07	97	11.83
23	5.44	48	8.09	73	10.14	98	11.89
24	5.56	49	8.18	74	10.22	99	11.96
25	5.69	50	8.27	75	10.29	100	12.02

Table 14. Flow Factors for Equation (4)

Measured Water Flow (gpm)	$(Q_2/Q_1)^{1.85}$
1	414.67
1.5	195.85
2	115.03
2.5	76.12
3	54.33
3.5	40.85
4	31.91
4.5	25.66
5	21.12
5.5	17.70
6	15.07
6.5	13.00
7	11.33
7.5	9.97
8	8.85
8.5	7.91
9	7.12
9.5	6.44
10	5.86
10.5	5.35
11	4.91
11.5	4.52
12	4.18
12.5	3.88
13	3.61
13.5	3.36
14	3.14
14.5	2.95
15	2.77
15.5	2.60
16	2.46
16.5	2.32
17	2.19
17.5	2.08
18	1.97
18.5	1.88
19	1.79
19.5	1.70
20	1.62

Table 15. Characteristics of Domestic Water Systems in Surveyed Residences

	House										
	1	2	3	4	5	6	7	8	9	10	11
1. K factor of nozzle	1.9	1.9	1.9	2.2	1.5	1.5	1.5	1.5	2.2	1.9	2.2
2. pipe type	M	M	M	M	M	M	M	L	L	L	L
3. 1/2" pipe											
Length	13	15	13	7	6	8	15	20	6	6	22
# of elbows	2	2	2	0	1	1	4	3	2	2	1
# of tees	1	1	1	1	1	1	0	1	1	1	1
4. 3/4" pipe											
Length	1	1	1	1	1	1	36	34	0	0	0
# of elbows	0	0	0	0	0	0	4	4	0	0	0
# of tees	0	0	0	0	0	0	8	7	0	0	0
5. Elevation change	5	-3	5	4	3	4	3	4	5	2	10

	House										
	12	13	14	15	16	17	18	19	20	21	22
1. K factor of nozzle	2.9	2.9	1.9	1.9	1.9	1.9	2.2	1.5	2.2	2.2	1.9
2. pipe type	L	L	L	L	L	L	PVC	PVC	PVC	PVC	L
3. 1/2" pipe											
Length	30	35	4	4	4	4	22	60	25	35	4
# of elbows	3	4	2	2	2	2	4	4	6	5	2
# of tees	1	1	1	1	1	1	1	1	1	1	1
4. 3/4" pipe											
Length	0	0	0	0	0	0	0	0	1	0	0
# of elbows	0	0	0	0	0	0	0	0	0	0	0
# of tees	0	0	0	0	0	0	0	0	0	0	0
5. Elevation change	5	3	3	3	4	4	3	3	3	3	0

Table 16. Analysis of Available Water Supply at Surveyed Residences

House Number	Measured Static Pressure (psi)	Measured Residual Pressure (psi)	Measured Water Flow Rate (gpm)	Calculated Maximum Water Flow Rate (gpm)
1	34	30.4	5.7	36.2
2	48	32.4	6.5	46.7
3	36	33.4	6.2	38.2
4	68	37.0	7.8	69.7
5	74	47.4	7.4	75.3
6	64	40.6	6.5	65.7
7	54	44.1	6.5	55.3
8	58	53.4	7.2	57.7
9	54	14.2	6.8	56.2
10	59	10.2	5.2	59.9
11	83	27.1	7.8	87.3
12	75	29.2	8.8	77.2
13	75	27.1	8.1	76.3
14	49	9.6	5.0	50.3
15	50	9.0	4.8	51.3
16	50	8.5	4.5	51.7
17	50	7.1	4.0	52.7
18	68	12.7	6.2	69.3
19	64	21.4	5.5	65.3
20	64	24.8	5.2	65.3
21	58	13.7	6.0	59.3
22	51	7.7	4.8	51.0

Table 17. Simplified Calculation Procedure to Determine the Characteristics of Residential Water Systems

1. Enter the distance D (in feet) (see Figure 3) ________ft

("D" is the horizontal distance from the cross-connection point to the faucet)

2. Enter the distance E (in feet) (see Figure 3) ________ft

("E" is the horizontal distance from the cross-connection point to the faucet)

3. Enter the distance F (in feet) ________ft

("F" is the vertical distance between the cross-connection point and the faucet)

4. Add lines 1, 2, and 3 ________ft

5. Multiply line 4 by 1.5 ________ft

6. Determine the K value for hose faucet ________

(see Figure 5 to identify faucet that most closely resembles faucet used in test or enter 2.0)

Flow water: Either use flow apparatus (go to step 7) or use domestic water meter and pressure gage (go to step 8).

7. Open faucet and allow to flow for 2 minutes or until gages become steady.

7.1 Enter flow rate ________gpm

7.2 Enter pressure ________psi

7.3 Multiply Line 6 by Line 6 ________

7.4 Divide 1.0 by Line 7.3 ________

7.5 Add 0.19 to Line 7.4 ________

7.6 Divide 1.0 by Line 7.5 ________

7.7 Determine square root of 7.6 ________

7.8 Divide Line 7.1 by Line 7.6 ________

7.9 Multiply Line 7.8 by Line 7.8 (square Line 7.8) ________psi

Proceed to step 9

8. Open faucet and return to meter. Determine volume of water flowed in 5 minute interval. (Note: No water may be flowed from any other outlet in residence during the 5 minute test interval)

8.1 Enter total flow in gallons _______gal

8.2 Divide Line 8.1 by 5 _______gpm

8.3 Divide Line 8.2 by Line 6 _______

8.4 Multiply Line 8.3 by Line 8.3 (square Line 8.3) _______psi

9. Friction Loss Calculation

9.1 Check the pipe type installed

Copper Type K ______ Copper Type M _____
Copper Type L ______ PVC _____

9.2 Friction factor from Table 8 for flow rate noted in Line 7.1 or Line 8.2 ______psi/ft

9.3 Multiply Line 5 by Line 9.2 _______psi

9.4 Add Line 7.9 or Line 8.4 to Line 9.3 _______psi

10. If a pressure reducing valve is present, see Table 11 for friction factor for flow rate noted in Line 7.1 or Line 8.2 (see Figure 4 for sketches of typical pressure reducing valves) _______psi

11. Calculation of Pressure Change due to Elevation change. Multiply Line 3 by 0.433 (if the test fixture is lower lower than the cross-connection point, multiply by -0.433) _______psi

12. Add Lines 9.4, 10 and 11 _______psi

13. Determine Static Pressure

13.1 Attach pressure gauge to faucet. Open faucet, record pressure _______psi

13.2 Add Line 11 to Line 13.1 _______psi

14. Calculate maximum available flow rate

14.1 Calculate pressure drop (PD) for measured water flow rate: Subtract Line 12 from Line 13.2 _______psi

14.2 Using Table 13, determine factor for PD noted on Line 14.1 _______

14.3 Using Table 13, determine factor associated

with static pressure, entered on Line 13.2 ________

14.4 Multiply Line 7.1 or 8.2 by Line 14.3 ________

14.5 Divide Line 14.4 by Line 14.2 ________gpm

**** If water flow rate on Line 14.5 is at least 26 gpm proceed ****
**** to Line 15. Otherwise, continue to summary on Line 17. ****

15. Calculate residual pressure at 26 gpm. (complete for proposed sprinkler system designs containing 3/4 and 1 inch pipe)

15.1 Using Table 14, determine flow factor for water flow rate entered on Line 7.1 or Line 8.2 ________

15.2 Multiply Line 14.1 by Line 15.1 ________psi

15.3 Subtract Line 15.2 from Line 13.2 ________psi

16. Calculate residual pressure at 18 gpm. (only complete for proposed sprinkler system designs containing 1 inch pipe)

16.1 Divide Line 15.1 by 1.97 ________

16.2 Multiply Line 14.1 by Line 16.1 ________psi

16.3 Subtract Line 16.2 from Line 13.2 ________psi

18. Summary

****

Available water supply is given as follows:

Static Pressure : ________ psi (from Line 13.2)

Residual Pressure : ________ psi (from Line 12)

________ gpm (from Line 7.1 or Line 8.2)

Maximum Available Water Flow Rate ________ (from Line 14.5)

Residual Pressure @ 18 gpm ________ psi (from Line 16.3)

Residual Pressure @ 26 gpm ________ psi (from Line 15.3)

****

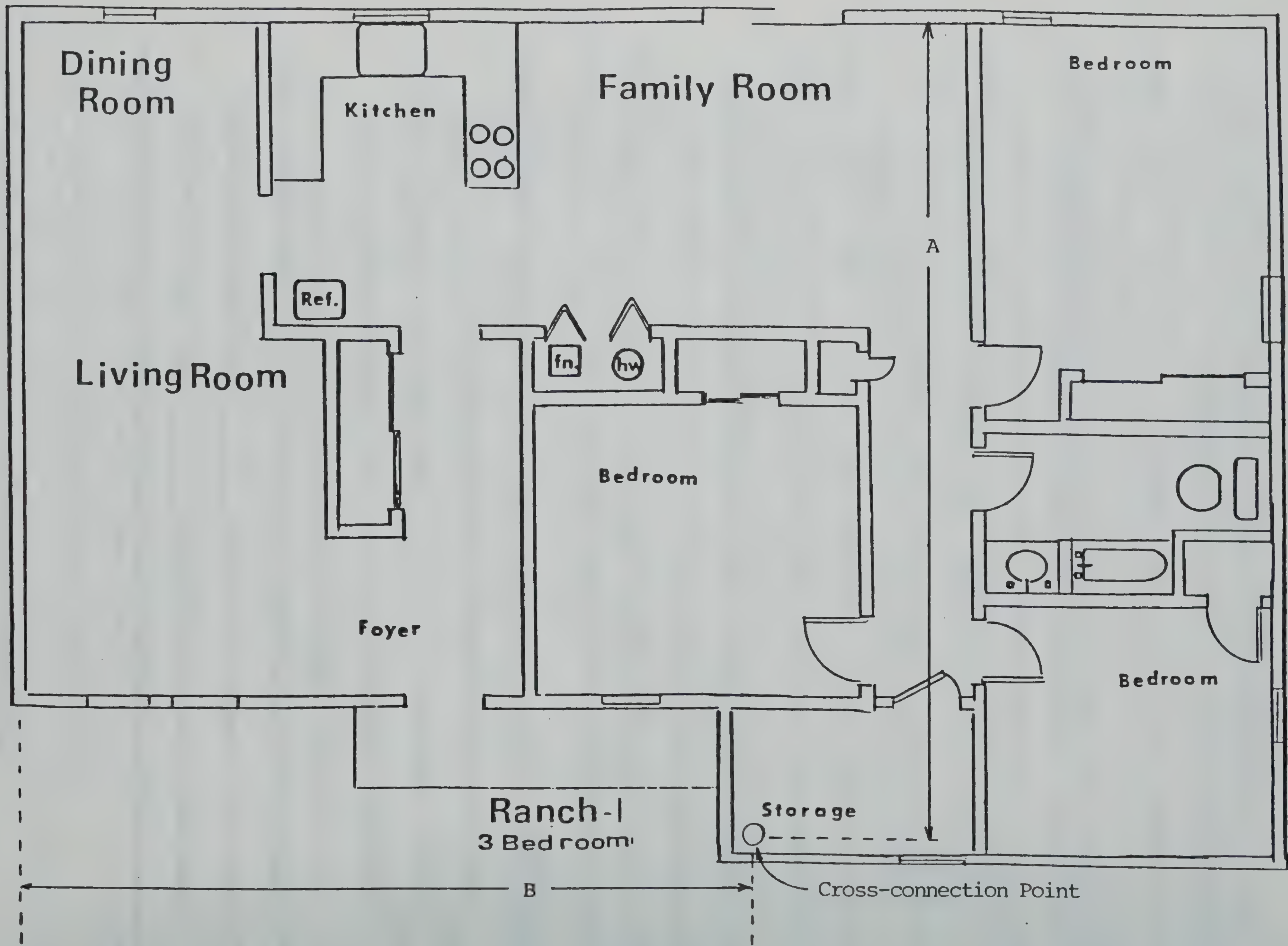
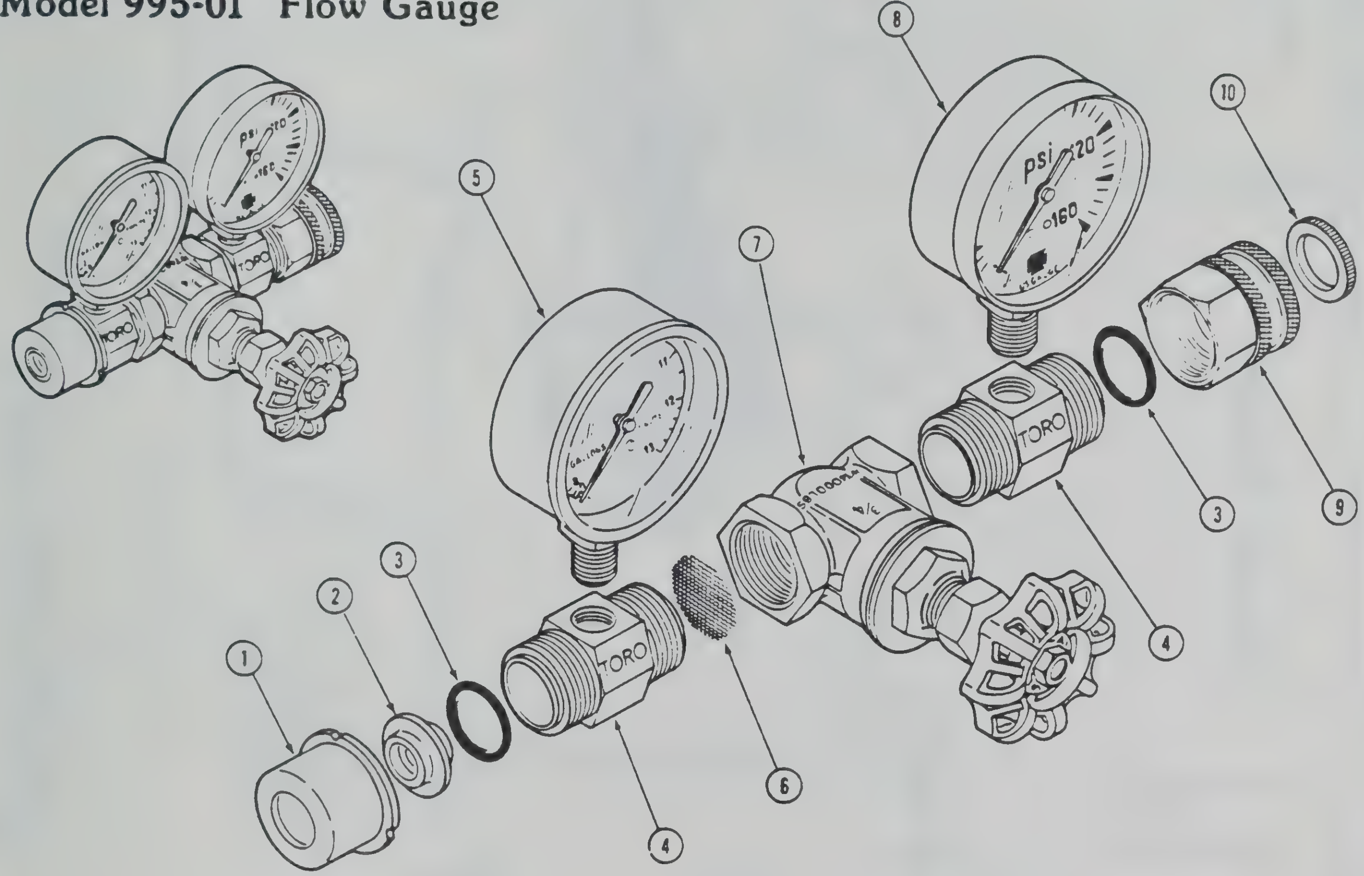


Figure 1. Dimensions for Calculation Procedure for Water Demand Requirements

Figure 2. Diagram of Measurement Apparatus

Model 995-01 Flow Gauge



Item No.	Part No.	Nomenclature	Item No.	Part No.	Nomenclature
1	9-4576	Threaded Insert - 3/4 Inch			
2	5-311	Orifice Plate			
3	360-0120	O-Ring (Qty. of 2)			
4	9-6023	Nipple (Qty. of 2)			
5	5-309	Flow Gauge			
6	5-307	Filter Screen			
7	5-301	Gate Valve - 3/4 Inch			
8	5-308	Pressure Gauge			
9	5-303	Hose to Pipe Fitting			
10	5-401	Hose Washer - 3/4 Inch			

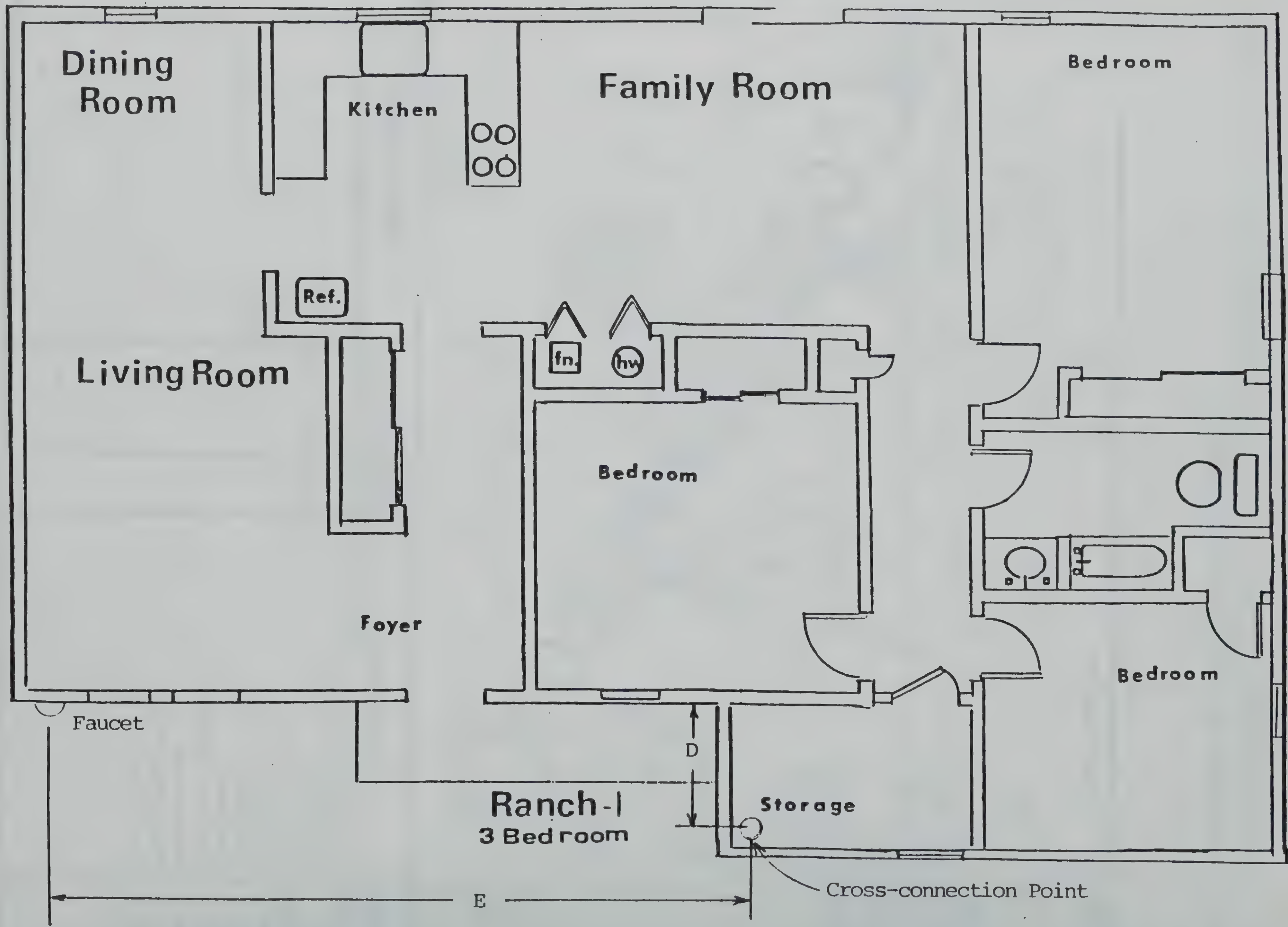


Figure 3. Dimensions of Domestic Water System for Simplified Calculation Procedure

Figure 4. Illustrations of Residential Pressure Reducing Valves

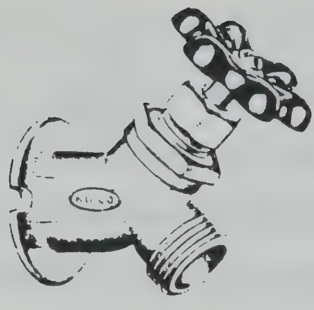
Figure 5. Illustrations of Typical Residential Plumbing Faucets

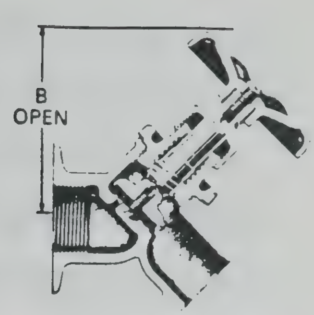
Anti-siphon/Frostproof
$k = 1.5$

Hose Bibb
$k = 1.6$

Frostproof
$k = 1.9$

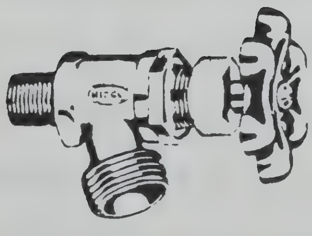
k = 1.9





4-5 Frostproof Lawn
k = 1.7

Boiler Drain
k - 2.2



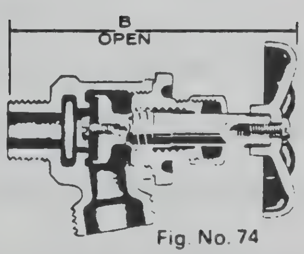


Fig. No. 74

Appendix A

Experimental Measurements of the Hydraulic Characteristics of Components of Domestic Water Systems

Two sets of experiments examining the hydraulic characteristics of components of domestic water systems are referred to in the report: one series conducted by Dubin and Landmesser and one series performed at the Center for Fire Research by a group of researchers from the Center for Fire Research and the University of Maryland. The experiments by Dubin and Landmesser have been described in detail elsewhere [13] and hence will not be repeated here. This discussion will review the latter series of experiments performed at the Center for Fire Research.

The principal purpose of the experiments at the Center for Fire Research is to assess the accuracy of the hydraulic characteristics of the various domestic water components presented in the report. The reported characteristics are based on manufacturers' literature or the experiments by Dubin and Landmesser. Specifically included are evaluations of the K factor for two randomly selected faucets and the friction loss through a residential PRV. In addition, use of the flow test apparatus illustrated in Figure 5 is examined.

A schematic diagram of the simulated domestic water system is presented in Figure A-1. Among the components included are a 3/4 inch residential flow meter and a 3/4 inch residential PRV. The PRV was removed from the system for half of the tests to study the influence of the PRV. If present, the PRV was set either in the "open" position (providing the least restriction to water flow) or the "closed" position (providing the greatest restriction to water flow). The flow apparatus was attached to

the faucet in half of the experiments to investigate the influence of the apparatus on the measurements and K value of the faucets.

Results from the series of experiments are indicated in Table A-1. The static pressure is reported at two locations, with gages located on either side of the PRV, to indicate the static drop across the PRV (the pressure difference across the PRV with no water flowing). The residual pressure is reported at four locations to assess the friction loss across the PRV and to determine the K values for the faucets and faucet - flow apparatus combination. The flow rate is reported by two independent means, including the flow apparatus and the residential style flow meter. In the latter case, the residential flow meter only records volume, with the flow rate determined by dividing the noted volume by the flow duration. The flow durations were sufficiently long to reduce the effects of any transient variations in the characteristics of the domestic water system.

The K value is determined by:

$$K = Q / P^{.05}$$

The value of flow rate, Q, used in the above equation was that measured by the residential flow meter. The residual pressure at gage 3 was used for the variable P in all cases, either with or without the flow apparatus.

Table A-1 Measurements from Tests of Simulated Domestic Water System

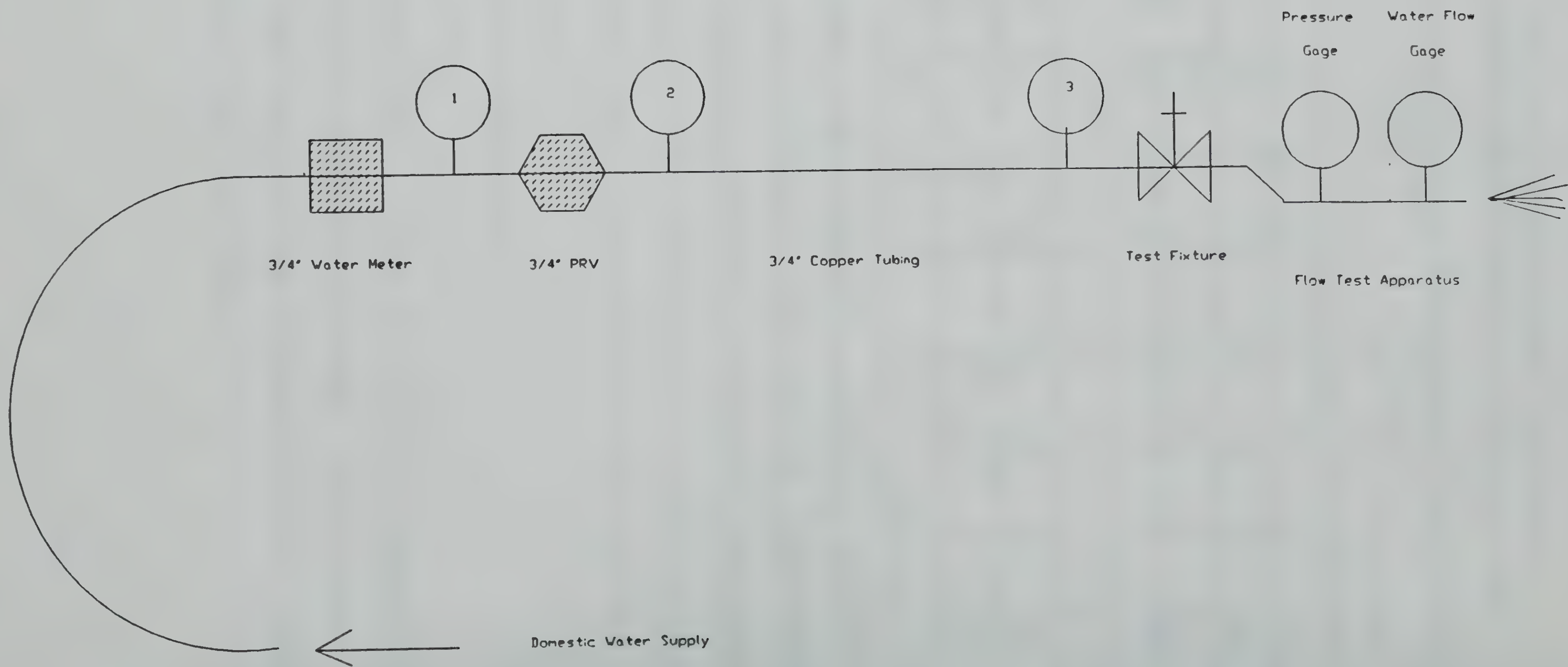
Faucet	PRV[1]	FA[2]	STATIC[3] (psi) 1	2	RESIDUAL[3] (psi) 1	2	3	FA	FLOW RATE[3] (gpm) FA	Flow Meter	K
Lawn	O	N	97	-	92	>60	38	-	-	12.6	2.04
	C	N	92	68	90	23	13	-	-	7.3	2.02
	NP	N	90	92	95	92	53	-	-	14.7	2.02
	O	Y	93	13	95	68	48	20	10.6	10.7	1.54
	C	Y	96	27	93	13	8	<10	4.7	4.2	1.48
	NP	Y	98	98	95	92	>60	27	12.5	12.4	-
Frost-proof	O	N	95	>60	95	66	31	-	-	13.6	2.44
	C	N	95	24	95	12	5	-	-	5.3	2.37
	NP	N	97	97	93	90	47	-	-	15.7	2.29
	O	Y	95	90	95	68	43	23	11.3	11.2	1.71
	C	Y	95	24	95	13	7	<10	5	4.4	1.66
	NP	Y	97	96	95	92	>60	32	13	13.2	-

[1]PRV Position: O = Open, C = Closed, NP = Not Present

[2]Flow Apparatus: N = Not Used, Y = Used

[3]See Figure A-1 for relative locations of pressure gages

Figure A-1. Schematic Diagram of Experimental Apparatus



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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This research effort developed a technique to assess the adequacy of the municipal water supply for residential sprinkler systems installed in one- and two-family dwellings. This effort is a continuation of a recently completed project which investigated cost-effective techniques for alleviation of deficiencies in the municipal water supply. In that effort, a need was identified to develop a technique to evaluate the adequacy of the municipal water supply.

This report includes characterizing typical plumbing flow fixtures in residences to permit an analysis of the domestic water supply within a residence. Having characterized the residential flow devices, techniques to evaluate the domestic water supply are investigated. This investigation considers the feasibility of developing an inexpensive prototype apparatus with which to conduct the water supply evaluations.

Based on the water supply evaluations, an assessment of the adequacy of typical domestic water systems for satisfying water demand requirements of residential sprinkler systems are documented. The water demand requirements for residential sprinkler systems were selected from the initial phase of this research which investigated techniques to alleviate water supply deficiencies.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

flow measurement; plumbing; residential buildings; sprinklers; water supply

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